[illegible] AND ENERGETICS OF WEED CONTROL IN SOYBEAN TILLAGE SYSTEMS

BY

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL
OF THE UNIVERSITY OF FLORIDA IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

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ACKNOWLEDGMENTS

I wish to express sincere appreciation to Dr. William Boggess, Dr Barry Brewes, Dr. Wayne Currey, Dr Richard Fluck, Mr. Timothy Hewitt, and Dr. David Teem. I especially acknowledge Dr. Currey and Dr. Teem for their continuous assistance and guidance throughout my graduate program. I truly appreciate the recognition that I received during the last five years. All of my awards and achievements are a direct reflection of these men and a result of the emphasis that they place upon their students.

Thanks are extended to Dr Raymond Cooper, Dr. Kenneth Quesenberry, and Mrs. Mary Ann Andrews My wife, Katie, and I extend sincere appreciation to all of our friends who have touched our lives in so many ways.

Finally, I dedicate this work to the past and to the future. The past symbolizes my late father, Martin A. Goette. I feel sure that he would have been proud of his son's accomplishments. The future can only be represented by my precious daughter, Elizabeth Virginia. Her presence has helped me to ultimately understand God's true meaning of happiness

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Abstract of Dissertation Presented to the Graduate
Council of the University of Florida in Partial
Fulfillment of the Requirements for the
Degree of Doctor of Philosophy

ECONOMICS AND ENERGETICS OF WEED CONTROL IN SOYBEAN TILLAGE SYSTEMS

By

John Martin Goette

April, 1984

Chairman: Dr. Wayne L. Currey
Major Department: Agronomy

Economic and energetic efficiencies of various weed control programs were determined and compared in three soybean [*Glycine max* (L.) Merr.] tillage systems. Field trials were conducted over a three year period between 1981 and 1983 at Gainesville, Florida. Weed control programs consisted of various combinations of preemergence and postemergence herbicide applications. Tillage operations were conventional, minimum, and no-tillage. Weed populations consisted primarily of alexandergrass [*Brachiaria plantaginea* (Link) A. Hitchc.], Florida beggarweed [*Desmodium tortuosum* (SW.) DC.], and redroot pigweed (*Amaranthus retroflexus* L.).

Herbicide treatments included oryzalin applied at 0.84 kg/ha, metribuzin at 0.43 kg/ha, acifluorfen at 0.43 kg/ha, sethoxydim at 0.22 and 0.34 kg/ha, 2,4-DB at 0.26 kg/ha, and glyphosate applied at 1.12 kg/ha.

Cost efficiencies were determined by establishing a cost efficiency ratio (CER = dollar return production cost^{-1}) for each weed control program within a given tillage system. CER values greater than unity indicated a profitable production system.

The energy efficiency was established by comparisons of energy productivity (EP = yield weight total energy input^{-1}). An average EP value for United States grown soybeans was approximately 0.1893 kg/MJ.

The comprehensive results indicated that preemergence applications of oryzalin and/or metribuzin were essential for maximizing economic and energetic efficiency. Postemergence applications were usually necessary in order to maintain maximum efficiency, however these treatments were relatively inefficient when they were applied alone.

Directed postemergence applications were the most consistent performing treatments among those tested. The directed postemergence treatment of (metribuzin + 2,4-DB), in combination with a preemergence application, produced the greatest single EP and CER across all tillage systems with two exceptions where it yielded the second highest value.

The no-tillage system produced an average EP of 0.083 kg/MJ and CER of 0.39 in 1981. In 1983, no tillage generated EP and CER values of 0.119 kg/MJ and 0.73, respectively. In 1982, however the conventional tillage system produced an average EP of 0.10 kg/MJ and CER of 0.44 which were significantly greater than the minimum and no-tillage operations. The variability in tillage system performance was primarily due to the fact that in-row subsoiling was not implemented in 1982 as it was in 1981 and 1983

CHAPTER 1

LITERATURE REVIEW

The Necessity for Improved Farm Productivity

In an address at the 1983 Beltsville Symposium concerning the problem of decreasing farm profits as a result of abundant food production, Dale E. Wolf pointed out,

> One solution to this problem is distressing: that the United States should decrease the rate at which agriculture production increases or at least reduce certain programs designed to increase or maintain efficient production.
>
> This "solution" to the "problem" is in some ways a neat one, it is even a plausible one. But the plight of the farmer in this country demonstrates that this solution is nevertheless wrong.
>
> Why? There is a moral, and basic survival, issue of cutting back food supplies in a world that desperately needs them. In fact, world grain stocks have been declining.
>
> There are other factors, moreover, that complicate the issue, e.g., declining land base and reduced availability of water. This is why it is more and more true that expansion of agriculture's capacity to produce will depend on gains in productivity now and in the future. (40, p. 14)

Excluding labor and farm real estate, U. S. agricultural inputs have continued to rise since 1975 (Figure 1). In light of the world

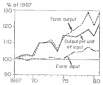

Figure 1. Farm productivity (36)

1980 preliminary, 1981 projected

population explosion coupled with a declining land base, the most feasible option for increasing the world food supply is to achieve more output per unit of farm input (36).

Economic Considerations

Since 1976, farm expenses have increased at a faster rate than commodity market prices (Figure 2) (36). Nineteen-eighty-three prices were forecasted to continue rising by approximately 2 to 4 percent, after increasing about 4 percent in 1982 (37).

In 1980, farms with sales of $200,000 and over represented only 4.3 percent of all the farms in the United States (Table 1). Although these farms were few in number, they accounted for approximately 50 percent of the total cash receipts. Farms with sales under $20,000 represented 61 percent of all farms, but received only 6.3 percent of the cash receipts (36).

Nineteen-eighty-three represented the first year in over 30 years in which total farm production expenses declined (37). This reduction was due to the idling of nearly 82 million acres of farmland partially implemented by the federal program to reduce surplus commodities known as the payment-in-kind program (5). Despite the projected 2 to 4 percent decline in 1983, farm production expenses have increased approximately sixfold over the past 23 years (Figure 3).

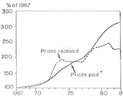

Figure 2. Prices received and paid by farmers (36, 37).

*Includes commodities and services, interest, taxes, and wage rates

F Forecast

TABLE 1. Cash receipts, net income, and farms by sales class (36).

Farms with Annual Sales of:	Cash Receipts		Net Income[a]		Farms	
	Millions	% of Total	Millions	% of Total	Thousands	% of Total
$200,000 and over	$ 69,685	49.8	$ 4,199	19.2	105	4.3
$100,000-$199,999	26,555	19.3	5,381	24.6	177	7.3
$40,000-$99,999	26,379	18.8	6,386	29.2	383	15.8
$20,000-$39,999	8,091	5.8	2,335	10.7	282	11.6
Under $20,000	8,824	6.3	3,556	16.3	1,481	61.0
All Farms	139,934	100.0	21,857	100.0	2,428	100.0

[a] Net income before adjustment for inventory change, 1980 data.

In examining the prices of selected farm inputs over the past six years, agricultural chemical costs have increased only slightly in comparison to all other production inputs (36, 37). Nineteen-eighty-three pesticide prices have been forecasted at 125 percent of 1977 costs (Figure 4).

Farm labor inputs have declined steadily since 1967, with this decline being partially due to the increase in applications of agricultural chemicals (Figure 5). Mechanical power and machinery have increased by nearly one-third while agricultural chemical usage has risen by over two-thirds (36).

Although pesticide applications have increased substantially over the past 15 years, their costs have remained relatively inexpensive (3). In considering average farm production expenses, pesticide costs represent approximately 3.29 percent of the total (Figure 6).

Over the past 16 years, herbicide sales have increased approximately fourfold (Figure 7) (35). In 1982, 195 million kilograms of herbicides were bought in the United States. This amount accounted for 53 percent of the entire volume of farm pesticide purchases. Insecticides represented 36 percent while fungicides accounted for 6 percent (3).

In 1976, field crops were produced on 138 million hectares within the United States. Only 77 million hectares, 56 percent, received herbicide applications for weed control (5).

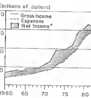

Figure 3. Farm income and expenses (37)

[a] Residual of gross farm income minus total production expenses.

Forecasts for 1982 and 1983.

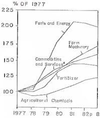

Figure 4 Farm input prices (36, 37).

P = preliminary, F = forecast
* Includes interest, taxes, and wages

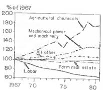

Figure 5. Use of selected farm inputs (36)

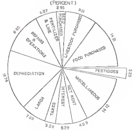

Figure 6. Average farm production expenses: 1978-1980 (31).

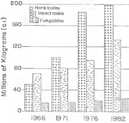

Figure 7 Volume of farm pesticide purchases (3).

The total monetary loss due to weeds in the 13 major field crops has been estimated to be approximately $5 billion per year. Losses in soybeans and corn were 33 and 30 percent, respectively, of the total. The average annual loss for all crops was appraised at $7.2 billion (6)

Shaw reported that weeds cause annual losses of approximately 10 percent in agricultural production (33, 34). This loss amounts to $12 billion per year. Each year, farmers spend $3.6 billion for herbicides and $2.6 billion for cultural, ecological, and biological methods of weed control. Monetary losses and the total cost of weed control add up to an annual figure of $18.2 billion (34).

In order for growers to maintain a relatively constant level of net income (Figure 3), they are being forced to implement production systems which are more efficient. As stated by Dale E. Wolf,

> it is, therefore, important to encourage new research and new technology—not as replacements of the old, but as building on the past. And further research is needed to help growers make the adjustments that can make the new knowledge useful.
>
> Research is crucial if we are to learn how to use crop-production chemicals more effectively and economically, thereby minimizing farm bankruptcies. (40, p. 14)

Energy Considerations

> Because only 16-18 percent of U S. energy supplies are used for producing, processing, distributing, and final consumer preparation of food, it is difficult to convince those involved that if energy is used more wisely here, worthwhile savings could result. But because neither the farmer nor the consumer can control the prices by which he buys or sells food, energy price changes impact severely Often the food processor, distributor, and marketer can pass on higher energy costs--but not the farmer or the consumer. (2, p. 32)

On-farm energy use in the United States is estimated at 2.25 trillion MJ per year (36). Total farm energy use in 1983 is expected to decrease 9 to 11 percent due to the payment-in-kind program (37). This reduction is not expected to influence the domestic energy market due to the fact that farm energy use consumes between 2.3 to 4.4 percent of the U.S. energy supply (19, 26, 29, 39).

Energy prices from 1967 to 1980 for diesel fuel, liquefied petroleum gas, and gasoline increased by approximately 500, 325, and 300 percent, respectively (Figure 8). Although labor costs rose 175 percent, the total farm labor force decreased 35 percent (Figure 5).

This continued rise in energy costs is the primary reason for the needed reduction in farm fuel consumption and the increase in fuel use efficiency. "Agricultural producers simply cannot shift back to lower energy-consuming technology without suffering serious losses in productivity. Such a step backward would require massive inputs of human labor" (24 p. 17).

In 1980, over 7.5 billion gallons of liquid fuels were used on farms in the United States (Figure 9) Throughout the six year period

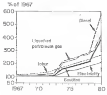

Figure 8. Energy prices paid by farmers (36).

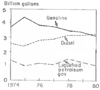

Figure 9. Farm fuel use (36)

between 1974 and 1980, overall gasoline consumption decreased while the use of diesel fuel rose steadily.

In 1980, the equivalent of 52.2 billion barrels of energy were supplied to world consumers (Table 2). Of the world energy supply, only 0.34 percent of it was consumed on farms within the United States (36).

Of all the inputs into U. S. agricultural production (11, 36), fertilizers and field machinery require the greatest amounts of energy and are estimated at 31.6 and 22.2 percent, respectively, of the total (Figure 10). Conversely, pesticides utilize only 4.9 percent or roughly 110 billion MJ per year. "Weed control practices have a very favorable energy input/output ratio because of the large increase in crop yields obtained from controlling weeds compared to the ratio for other agricultural operations" (25 p. 19). Table 3 illustrates some of the ways in which weed control reduces overall crop production energy requirements (1).

J. D. Nalewaja commented on weed science and its function in the "energy equation" by saying that

> weed scientists world-wide have made great contributions to greater agricultural production by developing efficient weed control practices. Our task demands that we also become publicly active in informing and promoting the adoption of weed control practices which will conserve energy without loss in effective crop production. And we will continue our research to improve herbicide efficiency, to integrate mechanical and cultural practices for more efficient and effective weed control. (25, p. 21)

G. H. Heichel examined the utilization of our energy resources by agricultural production and reported that

> the possibility that growing raw agricultural commodities might require 60 to 100 percent more fuel

TABLE 2. World energy supply (36).

	1970	1975	1978	1979	1980
	billion barrels* per year				
Total energy supply	38.0	44.2	50.4	52.1	52.2
	percentage share				
Energy Type:					
Petroleum	48	48	48	47	44
Natural gas	18	19	18	19	20
Coal	32	31	27	27	28
Nuclear	NA	NA	2	2	2
Hydro, other	2	2	4	5	6

* One barrel equals 159 liters.

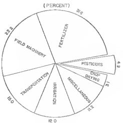

Figure 10. Energy used in agricultural production (11, 36).

TABLE 3 Contribution of weed control to crop production energy requirements (1).

Weed Control Reduces:	
Hand tillage costs	Hectares needed for crop production
Mechanical tillage costs	Harvest costs
Fertilizer costs	Grain drying cost
Irrigation Costs	Transporation and storage costs
Crop yield losses	Number of laborers needed

> energy in the next quarter-century emphasizes the need to develop energy frugal and environmentally sound food production strategies for the future. Significant differences in the efficiency with which energy is used exist among our present cropping systems, and widespread adoption of the more efficient systems could save fuel resources. Additional ways of producing more food with less energy are urgently needed. (20, p. 72)

Conservation Tillage

As defined by Pierre Crosson,

> conservation tillage includes tillage systems that create as good an environment as possible for the growing crop and that optimize conservation of our soil and water resources, consistent with sound economic practices. Conservation tillage is synonymous with maximum or optimum retention of residues on the soil surface and the utilization of herbicides to control weeds where tillage is not or cannot be performed. (8, p. 1)

No-tillage is considered an extreme form of conservation tillage. No-tillage is defined as placing the crop seed into the soil by a device that opens a slot sufficiently wide or deep to receive the seed, to provide satisfactory seed coverage, and to allow adequate root penetration.

Table 4 illustrates the degree to which conservation tillage was utilized in the United States by region in 1979 (8). Conservation tillage practices were utilized on 33.5 percent of the cropland harvested in the southeastern region of the United States. The southeast region had the highest percentage of the ten regions surveyed.

TABLE 4. Conservation tillage by region (8).

Region	1979	
	Million Hectares	Percentage of Cropland Harvested
Northeast	0.97	18.2
Lake States	2.81	17.9
Corn Belt	8.79	28.7
Northern Plains	10.12	33.3
Appalachia	2.36	30.7
Southeast	2.06	33.5
Delta	0.55	7.0
Southern Plains	0.80	6.1
Mountain	2.60	24.8
Pacific	0.95	13.5
TOTAL	32.01	23.1

In 1979, conservation tillage was employed on 23 percent of the cropland harvested in the United States. Reductions in tillage operations occurred on an estimated 32 million hectares (Table 4).

Robertson, Gallaher, and Prine (30) proposed several advantages of conservation tillage. Planting by the no-tillage method conserves fuel since fewer trips over the field are needed. This allows greater management flexibility since land preparation is not necessary. Land use may also be intensified due to the possibility of planting a second crop without a delay.

There is a lower overall investment for machinery. The maintenance cost of machinery is usually much lower since only one machine is required. It is also possible to farm lower cost land due to the fact that no-tillage allows the planting of row crops on sloping land.

Higher yields often occur with the no-tillage practice. Other benefits include decreased erosion due to a reduction of surface water runoff, improvement of soil structure because of the saving of organic matter, and greater water penetration with less loss from evaporation.

Although there are many advantages to conservation tillage, several disadvantages exist (4, 27, 29, 30, 31). These limitations include

(1) Soil temperature. Average soil temperature tends to be lower in soils under conservation tillage. This results from a reduction in soil radiation absorption and is a distinct disadvantage in northern areas.

(2) Insects. Pests, particularly soil insects, can be more troublesome when heavy mulches of winter cover crops are used.

(3) Management ability. With fewer alternatives to correct errors, a higher managerial level is required

(4) Soil Texture. No-tillage performs best on course and medium textured soils.

(5) Increased amount of seed. Farmers commonly plant 10 percent more seed due to inadequate seed-soil contact in rough seed beds. This problem may be alleviated by using subsoiler attachments.

(6) Weed control. There is a greater reliance on herbicides for weed control programs. Proper timing of herbicide applications, calibration of equipment, and the potential use of postemergence directed sprays need to be included in the management plan.

(7) Allelopathy. Rice described allelopathy as any direct or indirect harmful effect of one plant (including microorganisms) on another through the production of chemical compounds that escape into the environment (28). Elliott, McCalla, and Waiss stated that "phytotoxicity associated with crop residues is a potential problem facing conservation tillage systems. Residues left on or near the soil surface frequently reduce growth and yields of the next crop as compared with those when residues are removed or when conventional tillage is used" (10, p. 131). Sanford reported an antagonistic effect on soybean growth from wheat when the straw was incorporated during land preparation. Varying intensities of soybean leaf yellowing occurred on all treatments which involved leaving straw on the land, but seemed to be more intense where straw was left on the surface either standing or shredded (30).

Table 5 shows the amount of fuel consumed by various field operations (7, 38). Also included in the table is the amount of time required to conduct these tillage and planting operations.

According to Frye et al., "conventional tillage requires a relatively large amount of fuel, much of which is used in the plowing operation. Since plowing, disking and some trips over the field with machinery are eliminated by no-tillage, a considerable amount of fuel is saved. Requirements for additional herbicides in no-tillage systems offset some but not all of the energy saved in machinery operations" (15, p. 76). Approximately 17 percent in energy savings can be realized in individual farming operations by no-tillage soybean production (Table 6).

In his analysis of pesticides and pest management, Crosson indicated a number of reasons why conservation tillage typically requires more herbicides than conventional tillage. His first reason is called the substitution effect. "Under specific conditions, a given level of weed control may be achieved either by tillage or by herbicides, or some combination of both. If control by tillage is reduced then a compensatory increase in the amount of herbicides applied is necessary to maintain the same level of control" (8, p. 10).

The author identified a second reason as the efficiency effect. "Apart from the substitution effect, more herbicide must be applied to achieve a given level of weed control because some of the herbicide gets tied up by the crop residue, a necessary concomitant of conservation tillage. Herbicide efficiency is thus reduced" (8, p. 10).

TABLE 5. Fuel and labor required for tillage and planting operations in soybean production (7, 38)

Operation	Diesel Fuel (liters/ha)	Labor (hours/ha)
moldboard plow	13.10	1.06
tandem disk	4.68	0.45
plant (conventional)	5.43	0.64
plant (no-tillage)	5.89	0.79
cultivate (1)	3.74	0.84
spray	1.87	0.37

TABLE 6 Comparison of energy requirements for conventional tillage and no-tillage of soybeans (15).

Management Input or Operation	Assumption	Energy Required	
		Conventional	No-Tillage
		(MJ)	
Machinery	11.64 kg/ha – conv.; 9.56 kg/ha – no-till	992	817
Fertilizer, P	45 kg P_2O_5/ha	339	339
K	70 kg K_2O/ha	322	322
Seed	57 kg/ha – conv.; 63 kg/ha –no-till	955	1055
Herbicides + Insecticides	2.27 kg/ha – conv.; 3 41 kg/ha – no-till	230	343
Plow	Moldboard	984	–
Disk	One Time	343	–
Plant	75 cm row spacing	348	348
Apply herbicides		71	71
Broadcast Fertilizer		75	75
Harvest		536	536
Transport Grain	2700 kg/ha (3 km)	373	373
Dry Grain	23 to 15% water	1696	1696
TOTAL		7194	5975

Crosson described a third explanation for the increased dependence on herbicides with conservation tillage as the environmental effect. "The surface residue accompanying conservation tillage usually reduces evaporation of soil water, so that soils typically are more moist with conservation tillage than with conventional tillage. The increased moisture improves the conditions for germination and growth of weeds" (8, p. 10).

In an effort to estimate the adoption of conservation tillage by the farming community, Pierre Crosson remarked, "I believe that economic factors will support the spread of conservation tillage to 50 to 60 percent of the nation's cropland by 2010. On the basis of present evidence about the environmental costs and benefits of conservation tillage, I believe society will actively encourage this spread" (8, p. 32).

The objectives of this research were (a) to establish and compare economic and energetic efficiencies of weed control programs in soybean tillage systems and (b) to determine the most efficient crop production system.

Economic assessments are useful in establishing present production efficiencies. Current weed control programs usually abide by these economic estimates. With fluctuating fuel costs and the exhaustion of our non-renewable resources, the importance of energy evaluations will increase. With the constant depletion of our fuel reserves, energy efficiency evaluations will give us foresight into the economic future.

CHAPTER II

ENERGETICS OF WEED CONTROL IN SOYBEAN TILLAGE SYSTEMS

Introduction

Alder et al. stated that weed science has experienced an energy transition with weed control shifting from all human energy, to animal energy, to petroleum-powered energy, and ultimately to chemical energy (1). The authors continued by saying that as of 1976, human labor supplied the energy for the control of approximately 5 percent of the weeds, tractors and cultural equipment for 40 percent, and herbicides were responsible for controlling 55 percent. "Herbicides have thus played a vital role in a shift of energy source and in a reduction of the total energy used for weed control" (1, p. 100).

Farm labor inputs have declined steadily since 1967 with this decline being partially due to the increase in applications of agricultural chemicals (Figure 11). Mechanical power and machinery have increased by nearly one-third while agricultural chemical usage has risen by over two-thirds (16).

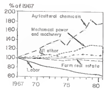

Figure 11. Use of selected farm inputs (36).

Over the past 16 years, herbicide sales have increased approximately fourfold (2, 35). In 1982, 195 million kilograms of herbicides were bought in the United States. This amount accounted for 53 percent of the entire volume of farm pesticide purchases. Insecticides represented 36 percent while fungicides accounted for 6 percent

Of all the inputs into agricultural production, fertilizers and field machinery require the greatest amounts of energy and are estimated at 31.6 and 22.2 percent, respectively of the total (36). Conversely, pesticides utilize only 4.8 percent or roughly 110 billion MJ per year (11, 36).

Energy prices from 1967 to 1980 for diesel fuel, liquefied petroleum gas, and gasoline increased by approximately 500, 325, and 300 percent, respectively (36). This continued rise in energy costs has made it necessary for reductions in fuel consumption and an increase in energy use efficiency.

"Productivity is the measure of how much product is obtained per unit of input" (12). Fluck proposed "that a new measure of productivity, the quantity of product per unit of input energy, be designated and that it be termed energy productivity.

Energy productivity is specific for each agricultural product, location, and time. That is, energy productivity can be used only to compare alternative production systems and energy conservation practices which result in the same product, at the same place, and at the same time" (12).

The objectives of this research were a) to establish and compare energetic efficiencies of weed control programs in soybean tillage systems and b) to determine the most energetically efficient crop production system.

Materials and Methods

Field trials were conducted over a 3 year period between 1981 and 1983 at Gainesville, Florida. These experiments were established at the University of Florida Agronomy Farm on an Arredondo fine sand, a well drained hyperthermic, siliceous, Grossarenic, Paleudult having pH 6.2 and 1.4 percent organic matter. Weed populations consisted primarily of alexandergrass [*Brachiaria plantaginea* (Link) A. Hitchc.], Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.] and redroot pigweed (*Amaranthus retroflexus* L.) (Appendices A, B, and C).

All herbicide treatments were applied with a CO_2 plot sprayer calibrated at 112 L/ha for preemergence applications and 187 L/ha for postemergence applications. The experiment was arranged in a split plot design with four replications. 'Bragg' soybeans were planted in rows spaced 76 cm apart with plot dimensions of 3 x 6 meters. Yields were taken from the middle two rows by means of a soybean plot thresher in 1981 and 1982. All four rows were harvested in 1983 by a soybean combine. The weed control programs evaluated in this experiment are given in Table 7.

Table 8 illustrates the energy inputs for the manufacture of herbicides (17, 18). This energy input is the product of the energy requirement for manufacturing and the rate of application. Units are in megajoules per hectare (MJ/ha).

TABLE 7. Weed control programs evaluated in 1981, 1982, and 1983 at Gainesville, Florida

Weed Control Program	Time of Application[a]
1. Weedy check	...
2. oryzalin	PRE
3 metribuzin	PRE
4. (oryzalin + metribuzin)[b]	(PRE)
5. acifluorfen	POST
6. sethoxydim	POST
7. acifluorfen + sethoxydim	POST + POST
8. oryzalin + acifluorfen	PRE + POST
9 metribuzin + sethoxydim	PRE + POST
10. (oryzalin + metribuzin) + acifluorfen + sethoxydim	(PRE) + POST + POST
11 (metribuzin + 2,4-DB)	(DP)
12 oryzalin + (metribuzin + 2,4-DB)	PRE + (DP)
13. metribuzin + (metribuzin + 2,4-DB)	PRE + (DP)
14. (oryzalin + metribuzin) + (metribuzin + 2,4-DB)	(PRE) + (DP)
15. hand weeded	...

[a] PRE = preemergence, POST = postemergence, DP = directed postemergence

[b] Parentheses signify a tank mix application

Table 6. Energy input for herbicide production

Herbicide	Rate	Energy Requirement[a]	Herbicide Energy Input[b]
	(kg/ha)	(MJ/kg)	(MJ/ha)
oryzalin	0.84	150	126
metribuzin	0.43	410	176
acifluorfen	0.43	250	108
sethoxydim	0.22–0.34	290	64–99
2,4-DB	0.28	95	27
glyphosate[c]	1.12	454	509

[a] Sources: Green, (17); Green and McCulloch, (18).

[b] Product of energy requirement and rate of application

[c] Preplant application in the no-tillage system.

The energy inputs required for tillage operations are given in Table 9. Inputs were composed of fuel consumption of 47.3 MJ/L (14) plus labor requirement at 74.25 MJ/hr (13).

Energy efficiency evaluations must consider the total energy input which encompasses all inputs of crop production. Items which should be included consist of seed, fertilizer, machinery, labor, and pesticides (28). The base energy input is defined as the estimated energy input for producing one hectare of soybeans less the inputs for tillage and weed control (Table 10). Total energy input (Table 11), upon which energy productivity is based, is the sum of base energy input (Table 10), tillage energy input (Table 9), and herbicide energy input (Table 8).

The parameter which was used to directly determine the energy efficiency was that of the energy productivity value which was calculated as follows.

$$EP = \frac{\alpha}{\beta+\gamma+\delta}$$

where

EP = energy productivity ($kg \cdot MJ^{-1}$)

α = yield ($kg \cdot ha^{-1}$) (Appendix E)

β = weed control energy input ($MJ \cdot ha^{-1}$)

γ = tillage energy input ($MJ \cdot ha^{-1}$)

δ = base energy input ($MJ \cdot ha^{-1}$)

TABLE 9. Energy inputs for tillage operations in 1981, 1982, and 1983, at Gainesville, Florida.

Tillage Operation[a,b]	Conventional	Minimum[c]	No-Tillage
	(MJ/ha)		
moldboard plow	698		
tandem disk	254	508	
plant (conventional)	305		
plant (no-tillage)		338	338
cultivate (1)	239	___	___
TOTAL INPUT	1496	846	338

[a] Inputs include fuel consumption [47.3 MJ/L (14)] plus labor requirement [74.25 MJ/hr (13)].

[b] Sources: Cromwell, (7); Vaughn et al., (38).

[c] 1981 required 1257 MJ/ha and consisted of plowing, disking, and planting.

TABLE 10. Base energy input for one hectare of soybeans (32).

Items	Unit	Quantity	Energy (MJ)
seed	kg	67.2	2251
lime	kg	739.2	976
potassium	kg	112.0	750
phosphate	kg	56.0	703
insecticide	kg	2.7	983
gasoline	L	68.0	2878
diesel	L	31.1	1486
machinery	kg	11.7	881
transportation	kg	184.0	202
labor	hr	3.6	268
TOTAL INPUT[a]			11,378

[a] Defined as the estimated energy input for producing one hectare of soybeans less the inputs for tillage and weed control.

TABLE 11. Total energy input of soybean production in 1981, 1982, and 1983, at Gainesville, Florida.

	Weed Control Program	1981			1982 and 1983[c]		
		Conventional	Minimum	No-tillage	Conventional	Minimum	No-tillage
		(MJ/ha)					
1	weedy check	12874[a]	12634	12342	12874	12334	12382
2	oryzalin	13117	13078	12595	13117	12467	12584
3	metribuzin	13167	13228	13635	13167	12517	13614
4	oryzalin + metribuzin	13293	13274	13761	13293	13043	12734
5	trifluralin	13089	13060	12307	13089	12449	12566
6	sethoxydim	13059	13051	13559	13035	13405	12523
7	acifluorfen + sethoxydim	13198	12958	13566	13286	12630	13749
8	oryzalin + acifluorfen	13342	13103	12810	13342	12632	12810
9	metribuzin + sethoxydim	13393	13144	12875	13348	12698	12816
10	oryzalin + metribuzin + acifluorfen + sethoxydim	13617	13378	13885	13688	13048	13167
11	metribuzin + 2,4-DB	13194	13395	13662	13184	12544	12662
12	oryzalin + metribuzin + 2,4-DB	13437	13178	12883	13437	12787	12885
13	trifluralin + metribuzin + 2,4-DB	13487	13248	12936	13487	12837	12955
14	oryzalin + metribuzin + [illegible] + 2,4-DB	13613	13376	13881	13613	12963	13131
15	hand weeded[b]	40074	41721	32734	39131	40146	40159

[a] Total energy values include the summation of the base input, tillage input, and weed control input (herbicide + application (117 MJ/ha)).

[b] Hand energy input calculated at 174.25 MJ/hr (13).

[c] Additional energy requirement in 1983 for conventional, minimum and no-tillage of [illegible] respectively.

Results and Discussion

Weed Control Programs

In examining all of the energy inputs that were utilized in the production of the soybean crop, the average herbicide energy input for this study was one of the smallest energy inputs with a value of 240 MJ/ha or approximately 2 percent of the base energy input. Despite the fact that the amount of energy consumed by the herbicide input was minimal, it had the most substantial effect on yield and subsequently on energy productivity.

In 1981, statistical analysis indicated a significant interaction between weed control programs and tillage systems (Table 12). Across all three tillage systems, the top six ranked energy productivity values were produced by weed control programs which contained preemergence applications of oryzalin and/or metribuzin. A specific example resulted in the minimum tillage system where all herbicide treatments which contained metribuzin as a preemergence application generated EP values that were significantly greater than all weed control programs which did not include a preemergence application of metribuzin. Postemergence applications were usually necessary to maintain maximum efficiency; however these treatments were relatively inefficient when they were applied alone in the conventional and minimum tillage systems.

Directed postemergence applications were the most consistent performing treatments among those tested. The directed postemergence treatment (metribuzin + 2,4-DB) in combination with a preemergence application produced the maximum EP values in the minimum and

TABLE 12. Energy productivity of weed control programs in soybean tillage systems in 1981 at Gainesville, Florida

Weed Control Program[a]	Tillage System		
	Conventional	Minimum	No-Tillage
	(kg/MJ)		
1. weedy check	g0.000e	g0.000b	f0.049b
2. oryzalin	h0.007de	g0.023b	f0.079ab
3. metribuzin	h0.066a-c	f0.113a	g0.090ab
4. (oryzalin + metribuzin)	g0.094a	f0.114a	h0.091ab
5. acifluorfen	h0.006de	g0.007b	f0.079ab
6. sethoxydim	g0.008de	h0.002b	f0.075ab
7. acifluorfen + sethoxydim	g0.024c-e	h0.018b	f0.085ab
8. oryzalin + acifluorfen	g0.041b-e	h0.021b	f0.106a
9. metribuzin + sethoxydim	h0.052a-d	f0.118a	g0.088ab
10. (oryzalin + metribuzin) + acifluorfen + sethoxydim	h0.075ab	f0.119a	g0.095ab
11. (metribuzin + 2,4-DB)	g0.042b-e	h0.007b	f0.052b
12. oryzalin + (metribuzin + 2,4-DB)	h0.040b-e	g0.044b	f0.097ab
13. metribuzin + (metribuzin + 2,4-DB)	g0.081ab	f0.123a	h0.075ab
14. (oryzalin + metribuzin) + (metribuzin + 2,4-DB)	h0.091a	f0.115a	g0.114a
15. hand weeded	h0.039c-e	g0.041b	f0.065ab

[a] Means within a row preceded by the same letter, or means within a column followed by the same letter are not significantly different at the 5% level of probability, as determined by Duncan's multiple range test.

no-tillage system while [illegible] contributed the second highest value in the conventional system

Energy efficiencies for weed control programs in 1982 were similar to those of the previous year in that the highest seven energy productivity values were produced by programs which contained preemergence applications of oryzalin and/or metribuzin (Table 13). Postemergence applications were again essential in maintaining efficiency but were energetically inefficient when applied alone. Energy productivity values increased significantly when these postemergence treatments were applied in combination with a preemergence application.

Directed postemergence treatments (metribuzin + 2,4-DB) applied in combination with preemergence applications of oryzalin, metribuzin, or (oryzalin + metribuzin) yielded the three highest energy efficiency values with (oryzalin + metribuzin) + (metribuzin + 2,4-DB) producing a maximum value of 0.165 kg/MJ. The herbicide program of (oryzalin + metribuzin) applied alone and in combination with acifluorfen + sethoxydim generated the fifth and fourth highest energy productivity values, respectively

Although a significant interaction resulted in 1983 between weed control programs and tillage systems, the overall results indicated that preemergence applications of oryzalin and/or metribuzin were essential for maintaining optimum weed control (Table 14). Across all three tillage operations, the top six rated energy productivity values were generated by weed control programs which included preemergence applications

TABLE 13. Energy productivity of weed control programs in soybean tillage systems in 1982 at Gainesville, Florida.

Weed Control Program[a]	Energy Productivity[b]
	(kg/MJ)
1. weedy check	0.013g
2. oryzalin	0.035e-g
3. metribuzin	0.076cd
4. (oryzalin + metribuzin)	0.089c
5. acifluorfen	0.036e-g
6. sethoxydim	0.020fg
7 acifluorfen + sethoxydim	0.050de
8. oryzalin + acifluorfen	0.044ef
9. metribuzin + sethoxydim	0.071cd
10. (oryzalin + metribuzin) + acifluorfen + sethoxydim	0.116b
11. (metribuzin + 2,4-DB)	0.040e-g
12. oryzalin + (metribuzin + 2,4-DB)	0.118b
13 metribuzin + (metribuzin + 2,4-DB)	0.135b
14. (oryzalin + metribuzin) + (metribuzin + 2,4-DB)	0.165a
15. hand weeded	0.042ef

[a] Means within a column followed by the same letter are not significantly different at the 5% level of probability, as determined by Duncan's multiple range test.

[b] No significant interaction resulted between weed control programs and tillage systems, therefore EP values include an average of all three tillage systems.

TABLE 14. Energy productivity of weed control programs in soybean tillage systems in 1983 at Gainesville, Florida

Weed Control Program^{a}	Tillage System		
	Conventional	Minimum	No-Tillage
	(kg/MJ)		
1. weedy check	g0.031b	f0.040b	e0.064cd
2. oryzalin	f0.051ab	g0.037b	e0.080b-d
3. metribuzin	f0.085ab	g0.053b	e0.142a-c
4. (oryzalin + metribuzin)	f0.111ab	g0.106ab	e0.129a-d
5. acifluorfen	f0.053ab	g0.050b	e0.119a-d
6. sethoxydim	f0.045b	g0.037b	e0.068cd
7. acifluorfen + sethoxydim	f0.081ab	g0.056b	e0.104a-d
8. oryzalin + acifluorfen	e0.107ab	f0.104ab	g0.103a-d
9. metribuzin + sethoxydim	f0.081ab	g0.076ab	e0.179a
10. (oryzalin + metribuzin) + acifluorfen + sethoxydim	g0.109ab	f0.116ab	e0.155ab
11. (metribuzin + 2,4-DB)	f0.051ab	g0.049b	e0.136a-d
12. oryzalin + (metribuzin + 2,4-DB)	g0.094ab	f0.101ab	e0.139a-c
13. metribuzin + (metribuzin + 2,4-DB)	f0.128a	g0.088ab	e0.172a
14. (oryzalin + metribuzin) + (metribuzin + 2,4-DB)	g0.100ab	f0.135a	e0.142a-c
15. hand weeded	g0.031b	f0.037b	e0.059d

[a] Means within a row preceded by the same letter, or means within a column followed by the same letter are not significantly different at the 5% level of probability, as determined by Duncan's multiple range test.

In each of the tillage systems, the highest energy productivity was delivered by weed control programs which contained a postemergence application. Directed postemergence treatments applied in combination with oryzalin and/or metribuzin yielded the maximum energy efficiency in the conventional and minimum tillage systems and produced the second highest value in the no-tillage system. The greatest EP value for the entire experiment occurred in the no-tillage system with the combination of metribuzin + sethoxydim which generated 0.179 kg/MJ.

Tillage Systems

In 1981, the no-tillage system produced an average EP of 0.083 kg/MJ which was greater than either the conventional or the minimum tillage system (Figure 12). This was due to the fact that 1981 was an extremely dry year and no-tillage was superior in soil water conservation.

Results in 1982 were different from 1981 and 1983, with the conventional tillage system generating an average EP of 0.10 kg/MJ. This value was significantly greater than the EP of both the minimum and the no-tillage systems. This was partially due to an abundant amount of rainfall in 1982 with an accumulation during the soybean growing season of 84.07 cm. During the same period of 1981, only 44.25 cm of rainfall were recorded (Appendix D).

The no-tillage system delivered the maximum energy productivity of 0.118 kg/MJ in 1983. The variability between years was primarily due to the fact that in-row subsoiling was not implemented in 1982 as it was in 1981 and 1983. In 1982, no-tillage soybeans were planted directly into the stubble through the use of fluted coulters. In 1981 and 1983, the in-row subsoilers provided optimum seed-soil contact which resulted in a more uniform soybean population. The difference in planting methods was dictated by equipment availability. Previous research had not indicated a significant yield increase due to in-row subsoiling (16).

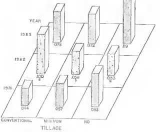

Figure 12 Energy productivity (kg/MJ) of soybean tillage systems in 1981, 1982, and 1983, at Gainesville, Florida. In 1982, bars with the same letter were not significantly different at the 5% level of probability, as determined by Duncan's multiple range test.

CHAPTER III

ECONOMICS OF WEED CONTROL IN SOYBEAN TILLAGE SYSTEMS

Introduction

In examining the prices of selected farm inputs over the past six years, agricultural chemical costs have only slightly increased in comparison to all other production inputs (36, 37). Nineteen-eighty-three pesticide prices have been forecasted at 125 percent of 1977 costs (Figure 13).

The use of herbicides in agriculture in the United States has increased approximately fourfold over the past 16 years (2, 35). The Office of Pesticide Programs of the Environmental Protection Agency (2) estimated that in 1982 $2 465 billion were spent on herbicides which accounted for approximately 64 percent of the total agricultural expenditure for pesticides in the United States.

Although pesticide applications have increased substantially over the past 15 years, their costs have remained relatively inexpensive. Average pesticide costs represent 3 28 percent of the total expense for farm production (2).

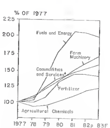

Figure 13. Farm input prices (36, 37).

P = preliminary; F = Forecast

*Includes interest, taxes, and wages

Throughout this 15 year period, total farm expenses have increased approximately threefold while commodity market prices have increased at a much slower rate (36, 37). In order for soybean growers to maintain a constant level of economic net return, they have been forced to implement production systems which are more efficient. Therefore, the continued rise in farm costs coupled with the growing acceptance of herbicide usage has made it difficult for the farmer to determine which weed control program is the most profitable.

The objectives of this research were a) to establish and compare economic efficiencies of weed control programs in soybean tillage systems and b) to determine the most economically efficient crop production system.

Materials and Methods

Field trials were conducted over a three year period between 1981 and 1983 at Gainesville, Florida. These experiments were established at the University of Florida Agronomy Farm on an Arredondo fine sand, a well drained hyperthermic, siliceous, Grossarenic, Paleudult having pH 6.2 and 1.4 percent organic matter. Alexandergrass [Brachiaria plantaginea (Link) A. Hitchc.], Florida beggarweed [Desmodium tortuosum (Sw.) DC.], and redroot pigweed (Amaranthus retroflexus L.) were the predominant weed species (Appendices, A, B, and C).

Herbicides were applied with a CO_2 plot sprayer calibrated at 112 L/ha for preemergence applications and 187 L/ha for postemergence applications. The experiment was arranged in a split plot design with four replications. 'Bragg' soybeans were planted in rows spaced 76 cm apart with plot dimensions of 3 x 6 meters.

TABLE 15 Weed control programs evaluated in 1981, 1982, and 1983, at Gainesville, Florida.

Weed Control Program	Time of Application[a]
1. weedy check	...
2. oryzalin	PRE
3. metribuzin	PRE
4. (oryzalin + metribuzin)[b]	(PRE)
5. acifluorfen	POST
6. sethoxydim	POST
7. acifluorfen + sethoxydim	POST + POST
8. oryzalin + acifluorfen	PRE + POST
9. metribuzin + sethoxydim	PRE + POST
10. (oryzalin + metribuzin) + acifluorfen + sethoxydim	(PRE) + POST + POST
11. (metribuzin + 2,4-DB)	(DP)
12. oryzalin + (metribuzin + 2,4-DB)	PRE + (DP)
13. metribuzin + (metribuzin + 2,4-DB)	PRE + (DP)
14. (oryzalin + metribuzin) + (metribuzin + 2,4-DB)	(PRE) + (DP)
15. hand weeded	...

[a] PRE = preemergence; POST = postemergence; DP = directed postemergence

[b] Parentheses signify a tank mix application.

Yields were taken from the middle two rows by means of a soybean plot thresher in 1981 and 1982. All four rows were harvested in 1983 by a soybean combine. Weed control programs which were evaluated in this experiment are given in Table 15.

Table 16 illustrates the herbicide costs for each year during 1981 through 1983. Expenses for tillage operations over this three year period are given in Table 17. Reductions of tillage costs occurred due to a slight decline in fuel prices since 1981.

Economic assessments must consider the total economic input which encompasses all costs of crop production. Items which should be included consist of seed, fertilizer, machinery, labor, and pesticides. The base economic input is defined as the estimated cost of producing one hectare of soybeans less the inputs for tillage and weed control (Table 18). The total cost of production (Tables 19, 20, and 21), upon which the cost efficiency ratio is founded, is the sum of base economic input (Table 18) (21, 21, 23), tillage cost (Table 17), and herbicide cost (Table 16).

The parameter which was used to directly determine the cost efficiency was the cost efficiency ratio which was calculated as follows:

$$CER = \frac{\alpha}{\beta+\gamma+\delta}$$

where

CER = cost efficiency ratio

α = yield value ($\$ \cdot ha^{-1}$) (Appendix E)

β = herbicide cost ($\$ \cdot ha^{-1}$)

γ = tillage cost ($\$ \cdot ha^{-1}$)

δ = base economic input ($\$ \cdot ha^{-1}$)

TABLE 16. Herbicide costs in 1981, 1982, and 1983.

Tillage Operation	Rate	Herbicide Cost 1981	1982	1983
	(kg/ha)	($/ha)		
oryzalin	0.84	20.39	25.48	24.56
metribuzin	0.43	22.54	22.30	19.95
acifluorfen	0.43	35.21	36.62	31.38
sethoxydim	0.22	51.89[a]	34.59	37.54
2,4-DB	0.28	3.01	4.32	3.63
glyphosate[b]	1.12	34.47	49.42	45.71

[a] Sethoxydim was applied at 0.34 kg/ha in 1981.

[b] Preplant application in the no-tillage system.

TABLE 17. Costs of tillage operations in 1981, 1982, and 1983, at Gainesville, Florida

Tillage Operation	Conventional			Minimum			No-Tillage		
	1981	1982	1983	1981	1982	1983	1981	1982	1983
	(\$/ha)^{a,b,c}								
moldboard plow	7.76	7.37	6.97	7.76					
tandem disk	2.99	2.85	2.73	2.99	5.70	5.46			
plant (conventional)	3.90	3.73	3.56	3.90					
plant (no-tillage)					4.36	4.18	4.56	4.36	4.18
cultivate (1)	4.05	3.90	3.79						
TOTAL COST	18.70	17.85	17.05	14.65	10.06	9.64	4.56	4.36	4.18

[a] Fuel cost (\$.317/L) + labor cost (\$3.40/hr) in 1981.

[b] Fuel cost (\$.282/L) + labor cost (\$3.35/hr) in 1982.

[c] Fuel cost (\$.261/L) + labor cost (\$3.35/hr) in 1983.

TABLE 18   Base economic input for producing one hectare of soybeans in 1981, 1982, and 1983, in north Florida (21, 22, 23).

	1981	1982	1983
	($/ha)		
Total cash expenses	396.95	400.12	387.69
Total fixed costs	98.91	102.07	103.76
Base economic input[a]	495.86	503.19	491.45

[a] Defined as the estimated cost for producing one hectare of soybeans less the costs for tillage and weed control.

TABLE 19 Total cost of soybean production in 1981 at Gainesville, Florida.

Weed Control Program	Conventional	Minimum	No-Tillage
	————	(\$/ha)	————
1. weedy check	514.56[a]	510.51[a]	540.88[a]
2 oryzalin	536.80	532.75	563.12
3. metribuzin	538.95	534 90	565 27
4. (oryzalin+metribuzin)	559.34	555 29	585.66
5. acifluorfen	551.62	547.57	577.94
6. sethoxydim	568.30	564.25	594.62
7 acifluorfen + sethoxydim	603.51	599.46	629.83
8. oryzalin + acifluorfen	573.86	569.81	600.18
9. metribuzin + sethoxydim	592 69	588.64	619.01
10. (oryzalin+metribuzin) + acifluorfen + sethoxydim	648 29	644.24	674.61
11. (metribuzin+2,4-DB)	541 96	537.91	568.28
12. oryzalin + (metribuzin+2,4-DB)	564.20	560.15	590.52
13 metribuzin + (metribuzin+2,4-DB)	566.35	562 30	592.67
14. (oryzalin+metribuzin) + (metribuzin+2,4-DB)	586.74	582.69	613.06
15. hand weeded	1759.16	1842.33	1612.02

[a] Total cost values include the summation of the base cost, tillage cost, and weed control cost (herbicide + application).

TABLE 20. Total cost of soybean production in 1982 at Gainesville, Florida.

Weed Control Program	Conventional	Minimum	No-Tillage
	———————	($/ha) ———	———————
1. Weedy check	521.04[a]	513.25[a]	558.75[a]
2. oryzalin	548.30	540.51	586.01
3 metribuzin	545.12	537.33	582.83
4. (oryzalin+metribuzin)	570.60	562.81	608.31
5. acifluorfen	559.44	551.65	597.15
6. sethoxydim	557.41	549.62	595.12
7. acifluorfen + sethoxydim	595.81	588.02	633.52
8. oryzalin + acifluorfen	586.70	578.91	624.41
9. metribuzin + sethoxydim	581.49	573.70	619.20
10. (oryzalin+metribuzin) + acifluorfen + sethoxydim	645.37	637.58	683.08
11. (metribuzin+2,4-DB)	549.44	541.65	587.15
12 oryzalin + (metribuzin+2,4-DB)	576.70	568.91	614.41
13. metribuzin + (metribuzin+2,4-DB)	573.52	565.73	611.23
14. (oryzalin+metribuzin) + (metribuzin+2,4-DB)	599.00	591.21	636.71
15. hand weeded	1630.15	2082.00	1838.91

[a] Total cost values include the summation of the base cost, tillage cost, and weed control cost (herbicide + application).

TABLE 21. Total cost of soybean production in 1983 at Gainesville, Florida.

Weed Control Program	Conventional	Minimum	No-Tillage
	—————	($/ha)	—————
1. weedy check	508.50[a]	501.09[a]	543.07[a]
2. oryzalin	534.79	527.38	569.36
3. metribuzin	530.18	522.77	564.75
4. (oryzalin+metribuzin)	554.74	547.33	589.31
5. acifluorfen	541.61	534.20	576.18
6. sethoxydim	547.77	540.36	582.34
7. acifluorfen + sethoxydim	580.88	573.47	615.45
8. oryzalin + acifluorfen	567.90	560.49	602.47
9. metribuzin + sethoxydim	569.45	562.04	604.02
10. (oryzalin+metribuzin) + acifluorfen + sethoxydim	627.12	619.71	661.69
11. (metribuzin+2,4-DB)	533.81	526.40	568.38
12. oryzalin + (metribuzin+2,4-DB)	560.10	552.69	594.67
13. metribuzin + (metribuzin+2,4-DB)	555.49	548.08	590.06
14. (oryzalin+metribuzin) + (metribuzin+2,4-DB)	580.05	572.64	614.62
15. hand weeded	2360.68	1951.91	1878.04

[a] Total cost values include the summation of the base cost, tillage cost, and weed control cost (herbicide + application).

Results and Discussion

Weed Control Programs

A significant interaction occurred in 1981 between weed control programs and tillage systems (Table 22). The comprehensive results determined that preemergence applications of oryzalin and/or metribuzin were necessary for maximizing cost efficiency.

In the conventional tillage system, the six highest cost efficiency ratios were produced by weed control programs which contained preemergence applications. The two optimum CER values resulted from (oryzalin + metribuzin) alone and in combination with the directed postemergence treatment of (metribuzin + 2,4-DB).

The top nine ranked weed control programs in the no-tillage system included preemergence applications. The primary difference that occurred was that (oryzalin + metribuzin) in combination with (metribuzin + 2,4-DB) proved to be significantly greater in cost efficiency than (metribuzin + 2,4-DB) alone.

When postemergence herbicides were applied alone in the minimum tillage system, they were economically inefficient. Any weed control program which included metribuzin as a preemergence application generated a CER value that was significantly greater than all weed control programs which did not contain a preemergence application of metribuzin.

The top seven ranked CER values in 1982 were generated by herbicide treatments that contained preemergence applications of oryzalin and/or metribuzin (Table 23). The four weed control programs which delivered the greatest economic return included postemergence applications of

TABLE 22. Cost efficiency ratios of weed control programs in soybean tillage systems in 1981 at Gainesville, Florida.

	Weed Control Program	Tillage System		
		Conventional	Minimum	No-Tillage
1	weedy check	h0.00f[a]	h0.00b[a]	g0.25b[a]
2.	oryzalin	i0.04ef	h0.12b	g0.39ab
3	metribuzin	i0.35a-d	g0.60a	h0.44ab
4.	(oryzalin+metribuzin)	h0.49a	g0.59a	i0.44ab
5.	acifluorfen	h0.03ef	h0.04b	g0.38ab
6	sethoxydim	h0.04ef	i0.01b	g0.35ab
7	acifluorfen + sethoxydim	h0.12ef	i0.08b	g0.38ab
8.	oryzalin + acifluorfen	h0.21c-f	i0.10b	g0.50a
9.	metribuzin + sethoxydim	i0.26b-e	g0.58a	h0.40ab
10.	(oryzalin+metribuzin) + acifluorfen + sethoxydim	i0.35a-d	g0.54a	h0.41ab
11	(metribuzin+2,4-DB)	h0.24c-e	i0.04b	g0.26b
12.	oryzalin + (metribuzin+2,4-DB)	i0.21c-f	h0.23b	g0.47ab
13.	metribuzin + (metribuzin+2,4-DB)	h0.42a-c	g0.64a	i0.38ab
14	(oryzalin+metribuzin) + (metribuzin+2,4-DB)	i0.46ab	g0.58a	h0.53a
15.	hand weeded	i0.20d-f	h0.21b	g0.32ab

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[a] Means within a row preceded by the same letter, or means within a column followed by the same letter are not significantly different at the 5% level of probability, as determined by Duncan's multiple range test.

Table [illegible]. Cost efficiency ratios of weed control programs in soybean tillage systems in 1982 at Gainesville, Florida.

Weed Control Program		Cost Efficiency Ratio[a]
1.	weedy check	0.06h[b]
2.	oryzalin	0.15gh
3.	metribuzin	0.34e
4.	(oryzalin+metribuzin)	0.38de
5.	acifluorfen	0.16gh
6.	sethoxydim	0.09gh
7.	acifluorfen + sethoxydim	0.21fg
8.	oryzalin + acifluorfen	0.19g
9.	metribuzin + sethoxydim	0.31ef
10.	(oryzalin+metribuzin) + acifluorfen + sethoxydim	0.46cd
11.	(metribuzin+2,4-DB)	0.18gh
12.	oryzalin + (metribuzin+2,4-DB)	0.51bc
13.	metribuzin+ (metribuzin+2,4-DB)	0.58ab
14	(oryzalin+metribuzin) + (metribuzin+2,4-DB)	0.63a
15	hand weeded	0.18gh

[a] No significant interaction resulted between weed control programs and tillage systems therefore CER values include an average of all three tillage systems.

[b] Means within a column followed by the same letter are not significantly different at the 5% level of probability, as determined by Duncan's multiple range test.

metribuzin + 2,4-DB) or acifluorfen + sethoxydim; however these postemergence treatments were economically inefficient when applied alone.

A significant interaction occurred in 1983 between weed control programs and tillage systems. The weed control results for this year were very similar to the two previous years in that preemergence applications of oryzalin and/or metribuzin were essential for maintaining optimum weed control (Table 24).

In each of the tillage systems, the highest economic return was delivered by weed control programs which contained a postemergence application. Directed postemergence treatments of (metribuzin + 2,4-DB) applied in combination with oryzalin and/or metribuzin yielded the maximum cost efficiency in the conventional and minimum tillage systems and produced the second highest value in the no-tillage system. The greatest CER value for the entire experiment occurred in the no-tillage system with the combination of metribuzin + sethoxydim.

Tillage Systems

The no-tillage system produced an average CER of 0.39 in 1981 (Figure 14). The minimum and conventional tillage systems yielded mean CER values of 0.29 and 0.23, respectively. Nineteen-eighty-one was an extremely dry year and no tillage was superior in soil water conservation.

TABLE 24. Cost efficiency ratios of weed control programs in soybean tillage systems in 1983 at Gainesville, Florida.

	Weed Control Program	Tillage System		
		Conventional	Minimum	No-Tillage
1	weedy check	g0.22cd[a]	f0.28b[a]	e0.41bc[a]
2	oryzalin	f0.36b-d	g0.25b	e0.51bc
3.	metribuzin	f0.60a-d	g0.36b	e0.90ab
4.	(oryzalin+metribuzin)	f0.76ab	g0.70ab	e0.79a-c
5.	acifluorfen	f0.36b-d	g0.34b	e0.74a-c
6	sethoxydim	f0.31b-d	g0.25b	e0.42bc
7.	acifluorfen + sethoxydim	f0.52a-d	g0.35b	e0.61a-c
8.	oryzalin + acifluorfen	e0.71a-c	f0.67ab	g0.62a-c
9.	metribuzin + sethoxydim	f0.54a-d	g0.49ab	e1.08a
10.	(oryzalin+metribuzin) + acifluorfen + sethoxydim	f0.69a-d	f0.63ab	e0.88a-c
11.	(metribuzin+2,4-DB)	f0.36b-d	g0.33b	e0.86a-c
12.	oryzalin + (metribuzin+2,4-DB)	f0.67a-d	f0.65ab	e0.86a-c
13	metribuzin + (metribuzin+2,4-DB)	f0.88a	g0.58ab	e1.07a
14	(oryzalin+metribuzin)+ (metribuzin+2,4-DB)	f0.67a-d	e0.87a	e0.86a-c
15	hand weeded	g0.20d	f0.23b	e0.37c

[a] Means within a row preceded by the same letter, or means within a column followed by the same letter are not significantly different at the 5% level of probability, as determined by Duncan's multiple range test.

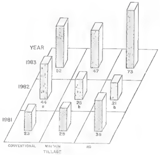

Figure 14 Cost efficiency ratio of soybean tillage systems in 1981, 1982, and 1983, at Gainesville, Florida. In 1982, bars with the same letter were not significantly different at the 5% level of probability, as determined by Duncan's multiple range test.

Results in 1982 were different from those in 1981 and 1983, with the conventional tillage system generating an average CER of 0.44 which was significantly greater than the minimum and no-tillage operations. This occurred partially as a result of an abundant amount of rainfall in 1982, with an accumulation during the soybean growing season of 84.07 cm, while 1981 received only 44.25 cm (Appendix D).

The no-tillage system produced an average CER of 0.73 in 1983, while the conventional and minimum tillage systems delivered average values of 0.52 and 0.47, respectively. The variability in tillage system performance between years was primarily due to the fact that in-row subsoiling was not implemented in 1982 as it was in 1981 and 1983. In 1982, a fluted coulter was used as the tillage device for planting into the no-tillage stubble. In 1981 and 1983, in-row subsoilers provided optimum seed-soil contact which rendered a more uniform soybean population. The two different planting methods occurred as a result of equipment availability. Previous research had not indicated a significant yield increase due to in-row subsoiling (26).

CHAPTER IV

SUMMARY AND CONCLUSIONS

Weed Control Programs

The average herbicide energy input in this study consisted of 240 MJ/ha or approximately 2 percent of the base energy input. Although the amount of energy required for manufacturing the herbicide was minimal, it had the most substantial effect on yield and subsequently on energy productivity.

Across all three tillage systems in 1981, the comprehensive results indicated that preemergence applications of oryzalin and/or metribuzin were essential for maximizing energetic and cost efficiency. A specific example resulted in the minimum tillage system where all herbicide treatments which contained metribuzin as a preemergence application generated EP and CBR values that were significantly greater than all weed control programs which did not include a preemergence application of metribuzin.

The directed postemergence treatment of (metribuzin+2,4-DB), in combination with a preemergence application, produced the maximum EP and CBR values in the minimum and no-tillage systems while it contributed the second highest value in the conventional program. Postemergence applications were usually necessary in order to maintain maximum efficiency; however these treatments were relatively inefficient when they were applied alone in the conventional and minimum tillage systems.

Th [illegible] EP and CER values in 1982 were generated by herbicide treatments that contained preemergence applications of oryzalin and/or metribuzin. Postemergence applications were again essential in maintaining efficiency but were energetically and economically inefficient when applied alone. Energy productivity and cost efficiency increased significantly when these postemergence treatments were applied in combination with a preemergence application.

Directed postemergence treatments of (metribuzin+2,4-DB) applied in combination with preemergence applications of oryzalin, metribuzin, and (oryzalin+metribuzin) yielded the three highest efficiency values with (oryzalin+metribuzin) + (metribuzin+2,4-DB) producing maximum EP and CER of 0.165 kg/MJ and 0.69, respectively. The herbicide program of (oryzalin+metribuzin) applied alone and in combination with acifluorfen + bentazon generated the fifth and fourth highest values, respectively.

Weed control results for 1983 were very similar to the two previous years. Preemergence applications of oryzalin and/or metribuzin were once again essential for maintaining optimum weed control.

In each of the tillage systems, the highest EP and CER values were delivered by weed control programs which contained a postemergence application. Directed postemergence treatments applied in combination with oryzalin and/or metribuzin yielded the maximum energy and cost efficiency in the conventional and minimum tillage systems while metribuzin + bentazon produced the highest efficiency in the no-tillage program.

Tillage Systems

The no-tillage system produced an average EP of 0.083 kg/MJ and CER of 0.39 in 1981. In 1983, no-tillage generated EP and CER values of 0.119 kg/MJ and 0.73, respectively. Results in 1982 were different from 1981 and 1983, where the conventional tillage system produced an average EP of 0.10 kg/MJ and CER of 0.44 which were significantly greater than the minimum and no-tillage operations.

The variability between years was primarily due to the fact that in-row subsoiling was not implemented in 1982 as it was in 1981 and 1983. In 1982, no-tillage soybeans were planted directly into the stubble through the use of fluted coulters. In 1981 and 1983, the in-row subsoilers provided optimum seed-soil contact which rendered a more uniform soybean population. The two different planting methods occurred as a result of equipment availability. Previous research had not indicated a significant yield increase due to in-row subsoiling (16).

Significant differences in production efficiency exist among current cropping systems. This research indicates that herbicides serve as excellent means for improving production efficiency. Continued research is needed to augment herbicidal use efficiency and to integrate chemical weed control with mechanical, cultural, and biological practices. Proper implementation of weed control technology in combination with conservation tillage can result in vast improvements in overall farm production efficiency.

"Agriculture does, of course, have a responsibility for improving its energy efficiency where it is feasible to do so, as do other segments of society. The real challenge is to identify and adopt production methods which reduce energy consumption but do not reduce productivity and profitability" (24, p. 17)

APPENDIX A
WEED CONTROL EVALUATIONS IN 1981 AT GAINESVILLE, FLORIDA

Weed Control Program	7-16-81[a]								
	Conv			Min.			No-Till		
	AG	PW	FB	AG	PW	FB	AG	PW	FB
1. weedy check	0	0	0	0	0	0	0	0	0
2. oryzalin	7.4	10	2	10	10	3.8	9.8	10	4.5
3. metribuzin	9.8	10	10	9.9	10	10	10	10	10
4. (oryzalin+metribuzin)	9.8	10	10	10	10	10	10	9.8	10
5. acifluorfen	2	10	3.3	1.5	10	4.8	5.5	10	6.8
6. sethoxydim	10	0	0	10	0	0	10	0	0
7. acifluorfen + sethoxydim	10	10	6.3	10	10	6	10	10	7.8
8. oryzalin + acifluorfen	9.8	10	5.8	9.5	10	6.8	9.8	10	8.3
9. metribuzin + sethoxydim	10	10	10	10	10	10	10	10	10
10. (oryzalin+metribuzin) + acifluorfen + sethoxydim	10	10	10	10	10	10	10	10	10
11. (metribuzin+2,4-DB)	0	0	0	0	0	0	0	0	0
12. oryzalin + (metribuzin+2,4-DB)	9.9	9.3	1.3	10	9.6	4.3	10	9	3.8
13. metribuzin + (metribuzin+2,4-DB)	10	10	10	10	10	10	10	10	10
14. (oryzalin+metribuzin) + (metribuzin+2,4-DB)	10	10	10	10	10	10	10	10	10
15. hand weeded	10	10	10	10	10	10	10	10	10

[a] Evaluations are based on the scale, 0-10, where 0 = zero weed control and 10 = complete weed control.

AG = alexandergrass
PW = redroot pigweed
FB = Florida beggarweed

APPENDIX B
WEED CONTROL EVALUATIONS IN 1982 AT GAINESVILLE, FLORIDA

Weed Control Program		8-27-82[a]								
		Conv.			Min.			No-Till		
		AG	PW	FB	AG	PW	FB	AG	PW	FB
1	weedy check	0	0	0	0	0	0	0	0	0
2.	oryzalin	6.5	8	1.8	7	7.3	0	7	7.8	1.3
3.	metribuzin	6.8	9.3	7.5	5.5	8.8	7	5.8	10	7.5
4	(oryzalin+metribuzin)	8.5	9.3	8.5	7.5	9.3	6.8	5.8	9.3	7
5	acifluorfen	3.3	10	4.3	3	9.3	1.8	0.8	9.3	1
6.	sethoxydim	8.5	1.3	1	8	0.5	0	7.8	0.5	0
7.	acifluorfen + sethoxydim	8.5	9.3	3.5	8	7.5	1.3	8.3	8.8	2.5
8.	oryzalin + acifluorfen	6.5	9.5	4.8	8.3	10	0	8.3	10	0.5
9.	metribuzin + sethoxydim	7.8	9.8	7.8	8.3	10	6.3	6	9.8	6.3
10.	(oryzalin+metribuzin) + acifluorfen + sethoxydim	9.8	10	9.0	10	10	7.3	9	10	7
11.	(metribuzin+2,4-DB)	5.5	6.8	7.3	3	6.3	4	2.3	7	6.8
12.	oryzalin + (metribuzin+2,4-DB)	8.3	9.8	8	7.8	9.3	6.5	9.3	9.8	8.3
13.	metribuzin + (metribuzin+2,4-DB)	7.8	10	9.5	8	10	9.3	7.8	10	10
14.	(oryzalin+metribuzin) + (metribuzin+2,4-DB)	10	10	10	9	9.5	9.5	8.5	10	10
15.	hand weeded	7.8	10	8.5	8.8	10	7.5	8.3	9.8	9.8

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[a] Evaluations are based on the scale of 0-10, where 0 = zero weed control, and 10 = complete weed control.

AG = alexandergrass
PW = redroot pigweed
FB = Florida beggarweed

APPENDIX C
[illegible] EVALUATIONS IN 1983 AT GAINESVILLE, FLORIDA

Weed Control Program	8-10-83[a]								
	Conv.			Min.			No-Till		
	AG	PW	FB	AG	PW	FB	AG	PW	FB
1. weedy check	0	0	0	0	0	0	0	0	0
2. oryzalin	8.7	7	1.5	6.8	7.0	1.8	9.8	8.3	1.3
3. metribuzin	7	8.8	8	8	9.3	7.3	7	9.8	8.3
4. (oryzalin+metribuzin)	9	9.3	9	9.8	9.8	8.5	9.8	9.8	8
5. acifluorfen	5	10	7.3	4.5	10	4.8	8	9.8	3.8
6. sethoxydim	10	0	0	10	0.8	0	10	0	0
7. acifluorfen + sethoxydim	9.5	10	6	10	8.8	4.3	10	9.3	4.8
8. oryzalin + acifluorfen	10	10	7.3	9.3	10	3.8	9.8	10	3.3
9. metribuzin + sethoxydim	10	9.8	8.8	10	8.8	7.3	10	9	7.5
10. (oryzalin+metribuzin) + acifluorfen + sethoxydim	10	10	10	10	10	8.8	10	9.8	8.8
11. (metribuzin+2,4-DB)	1	8	8	3	4	5	4.8	7.8	8
12. oryzalin + (metribuzin+2,4-DB)	8	9.3	9.8	8	8.8	8.3	8.8	9.5	9.5
13. metribuzin + (metribuzin+2,4-DB)	9.3	10	10	7.5	9.3	10	9.3	10	10
14. (oryzalin+metribuzin) + (metribuzin+2,4-DB)	9.8	10	10	9.8	10	10	9.8	10	10
15. hand weeded	9.5	10	9.3	10	10	10	10	10	9.8

[a] Evaluations are based on a scale of 0-10, where 0 = zero weed control, and 10 = complete weed control.

AG = alexandergrass
PW = redroot pigweed
FB = Florida beggarweed

APPENDIX D

MONTHLY PRECIPITATION IN 1981, 1982, AND 1983 AT GAINESVILLE, FLORIDA

Year	Month	Precipitation In Centimeters
1981		
Total for May through October -44.25	May	2.11
	June	17.25
	July	7.39
	August	12.65
	September	2.79
	October	2.06
1982		
Total for May through October - 84.07	May	7.90
	June	22.20
	July	17.17
	August	15.70
	September	18.03
	October	3.07
1983		
Total for May through October - 80.90	May	10.67
	June	25.50
	July	9.30
	August	4.17
	September	27.81
	October	3.45

APPENDIX E

[illegible] YIELDS OF WEED CONTROL PROGRAMS IN SOYBEAN TILLAGE SYSTEMS IN 1981, 1982, and 1983 AT GAINESVILLE, FLORIDA

	Weed Control Program	Soybean Yield [a]						
		1981			1982[b]	1983		
		Conventional	Minimum	No-Tillage		Conventional	Minimum	No-Tillage
		(kg/ha)						
1	weedy check	1	0	603	166	399	489	790
2	oryzalin	87	290	993	445	669	461	1007
3	metribuzin	861	1458	1122	971	1119	863	1794
4	(oryzalin+metribuzin)	1243	1484	1162	1148	1476	1340	1646
5	acifluorfen	82	30	988	457	634	623	1496
6	sethoxydim	102	32	940	253	588	459	852
7	acifluorfen + sethoxydim	315	227	1076	644	1076	707	1326
8	oryzalin + acifluorfen	549	268	1360	570	1428	1320	1319
9	metribuzin + sethoxydim	688	1545	1122	920	1081	965	2294
10	(oryzalin+metribuzin) + acifluorfen + sethoxydim	1018	1582	1238	1543	1493	1514	2041
11	(metribuzin+2,4-DB)	553	87	658	512	673	615	1742
12	oryzalin + (metribuzin+2,4-DB)	535	573	1244	1539	1317	1292	1754
13	metribuzin+(metribuzin+2,4-DB)	1084	1617	1019	1768	1726	1130	2228
14	(oryzalin+metribuzin) + (metribuzin+2,4-DB)	1233	1535	1484	2181	1361	1750	1858
15	hand weeded	1557	1714	2326	1921	1120	1707	2405

[a] Soybean yield value calculated at 0.221, 0.193, 0.285 $/kg for 1981, 1982, and 1983, respectively.

[b] No significant interaction resulted between weed control programs and tillage systems, therefore yields in 1982 include an average of all three tillage systems.

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He is a member of Alpha Zeta honorary society, Phi Kappa Phi honorary society, Florida Weed Science Society, Southern Weed Science Society, and Weed Science Society of America.

John M. Goette is married to the former Katie B. Hays and they have one child, Elizabeth Virginia.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Wayne L Currey

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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